US006587191B2

(12) **United States Patent**
Greenfield et al.

(10) **Patent No.:** **US 6,587,191 B2**
(45) **Date of Patent:** **Jul. 1, 2003**

(54) **IN-ACTION BORESIGHT**

(75) Inventors: **Jonathan Greenfield**, Haifa (IS); **David Zarchi**, Kiryat Tivon (IS); **Hai Pedut**, Haifa (IS); **Ram Lebber**, Mosgov (IS)

(73) Assignee: **Rafael-Armament Development Authority Ltd.**, Haifa (IL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/746,002**

(22) Filed: **Dec. 26, 2000**

(65) **Prior Publication Data**

US 2002/0026740 A1 Mar. 7, 2002

(30) **Foreign Application Priority Data**

Dec. 30, 1999 (IS) 133835

(51) **Int. Cl.**^{7} **G01B 11/26**; G01B 21/02; G01B 7/00

(52) **U.S. Cl.** **356/139.07**; 244/3.16; 244/3.13; 250/203.2; 356/141.1

(58) **Field of Search** 244/3.13, 3.16; 356/139.07, 141.1; 89/41.06, 41.05; 250/203.2

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,274,735 A * 6/1981 Tamura et al.
5,007,736 A * 4/1991 Daniel et al.
5,456,157 A * 10/1995 Lougheed et al. 89/134
5,786,889 A * 7/1998 Pope et al. 356/141.1
5,838,014 A 11/1998 Cabib et al.
6,021,975 A * 2/2000 Livingston 244/3.13
6,331,887 B1 * 12/2001 Shiraishi et al. 356/3.03

FOREIGN PATENT DOCUMENTS

EP 0735341 A1 10/1996
EP 0992759 A1 4/2000
GB 2165957 10/1984

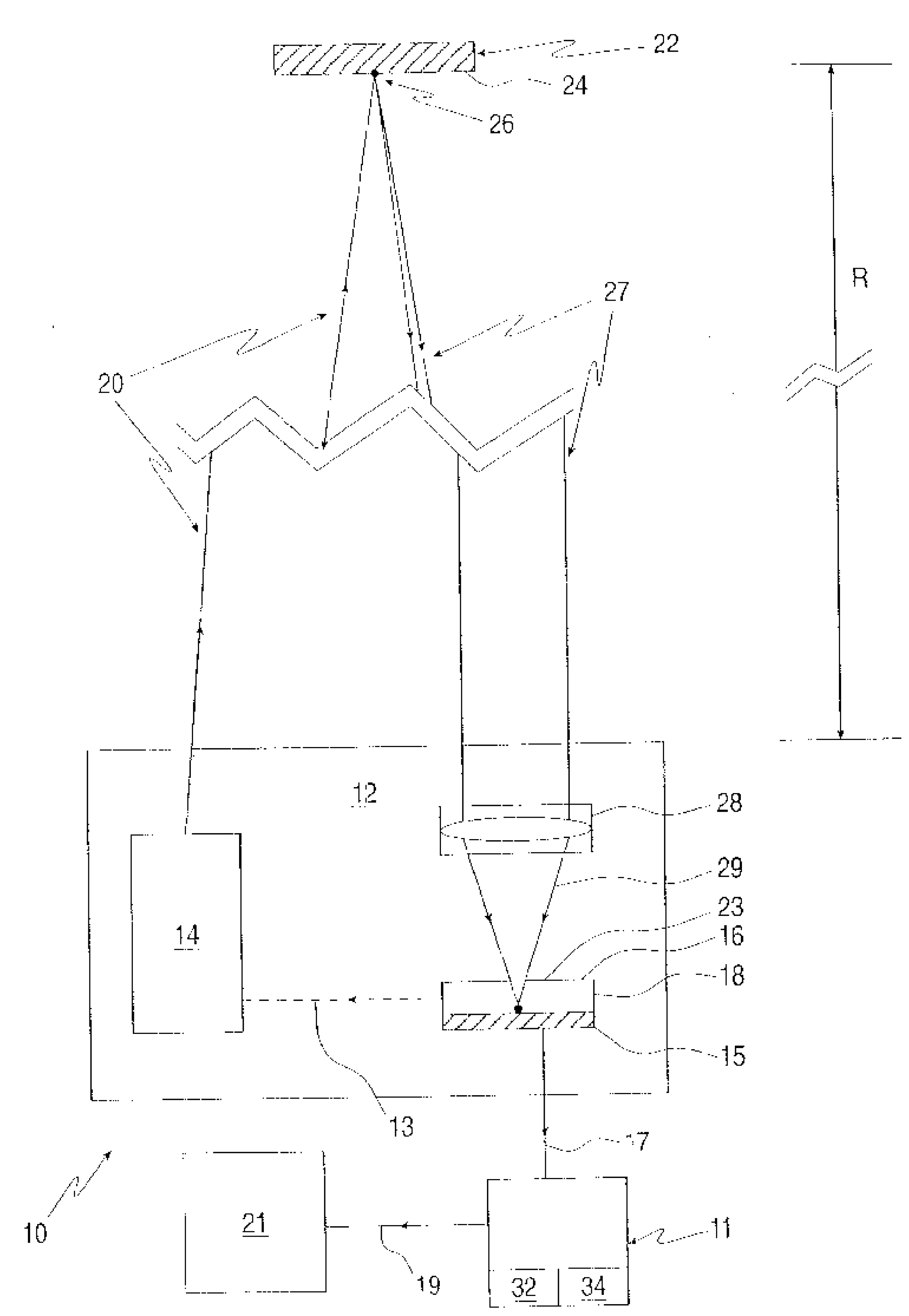
* cited by examiner

Primary Examiner—Stephen C. Buczinski
(74) *Attorney, Agent, or Firm*—Mark M. Friedman

(57) **ABSTRACT**

A method for boresighting of a designation system, including a tracker responsive to a detector with reference to an indicator, including the step of directing a beam of light at a target, using a light source, so that the beam of light is reflected from a spot on the target while a temperature of the spot remains substantially constant. The method further includes focusing at least part of the reflected light as an image on the detector and determining a misalignment of the indicator and the image.

6 Claims, 4 Drawing Sheets



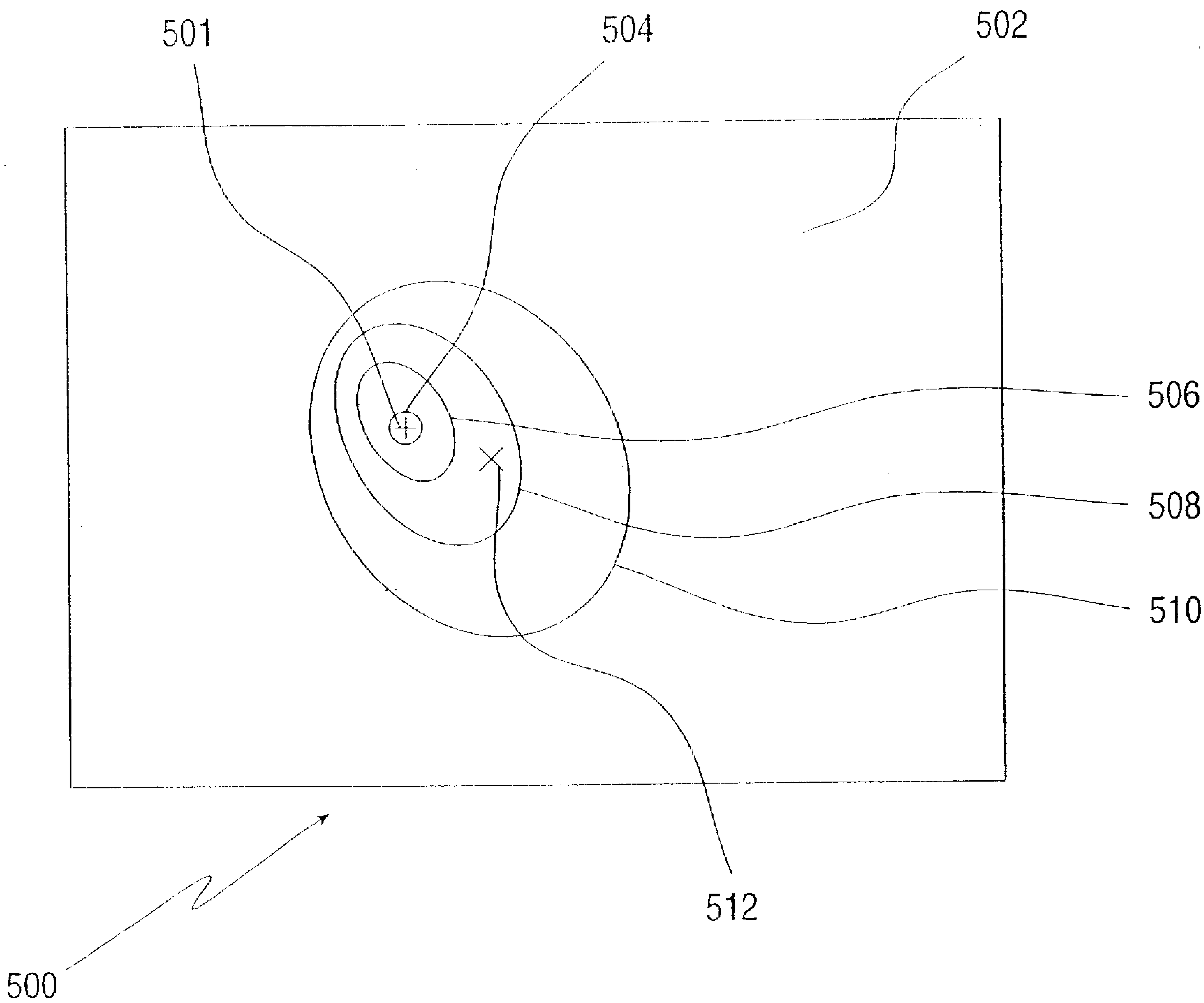


FIG.1 (Prior art)

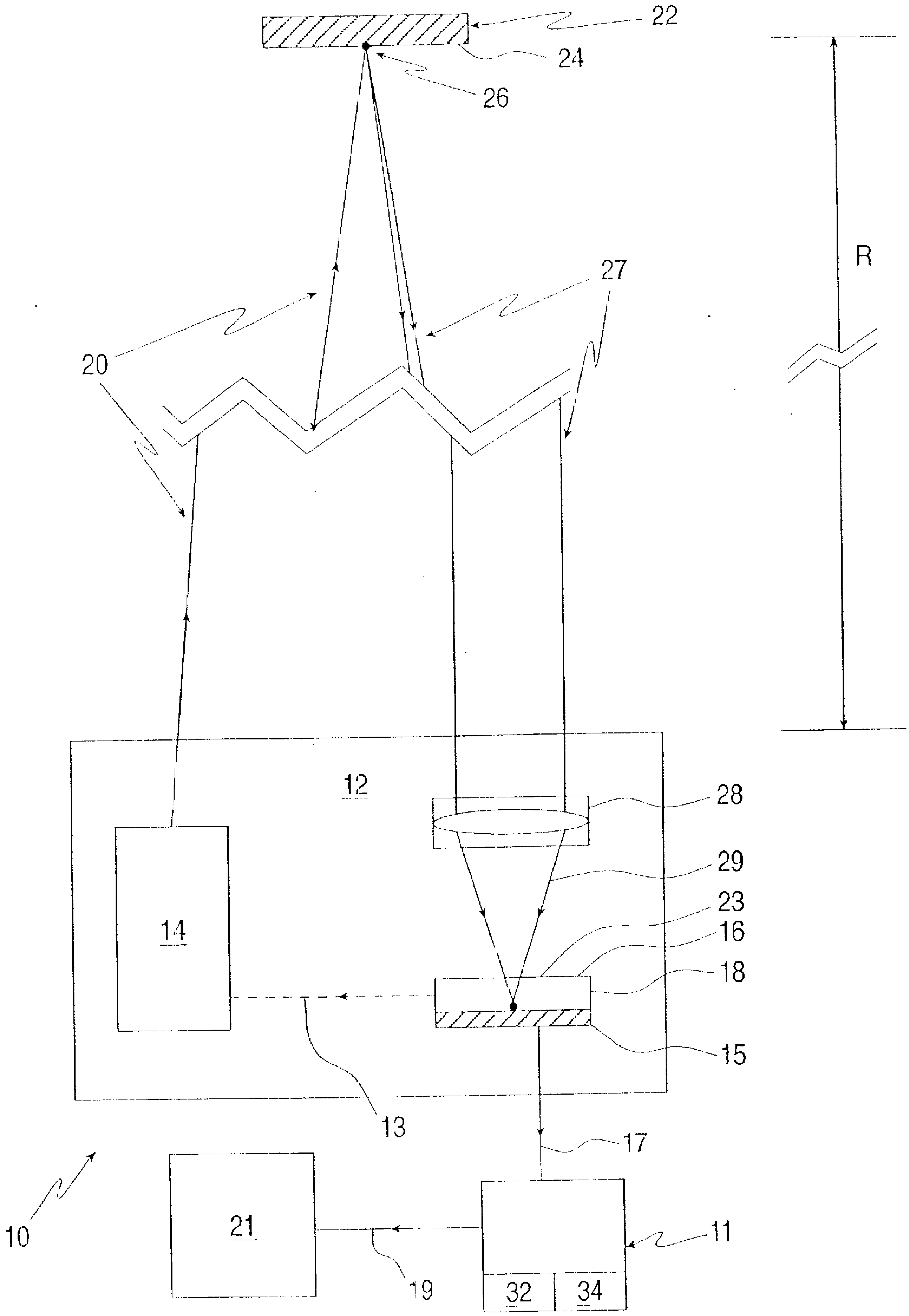


FIG.2

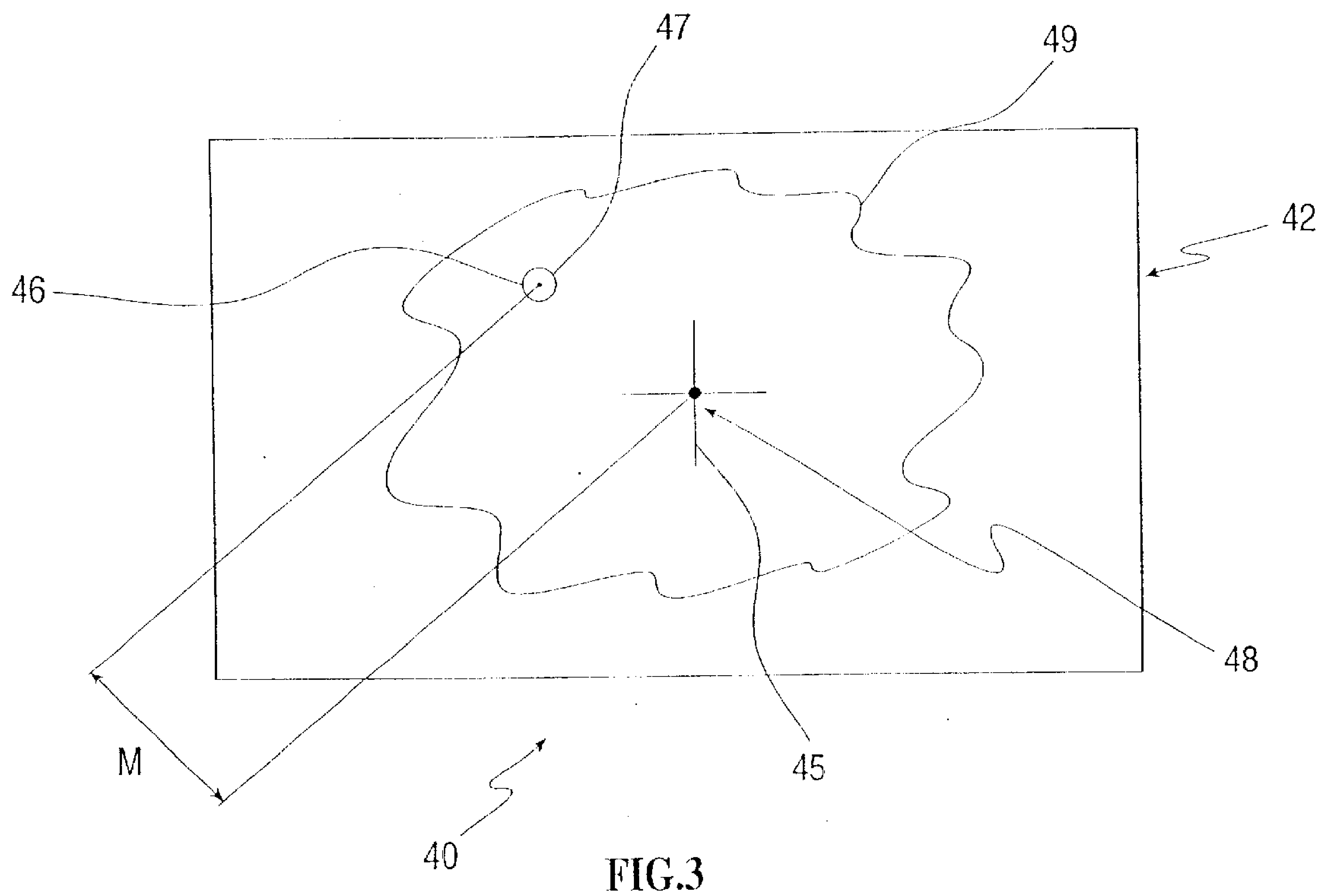


FIG.3

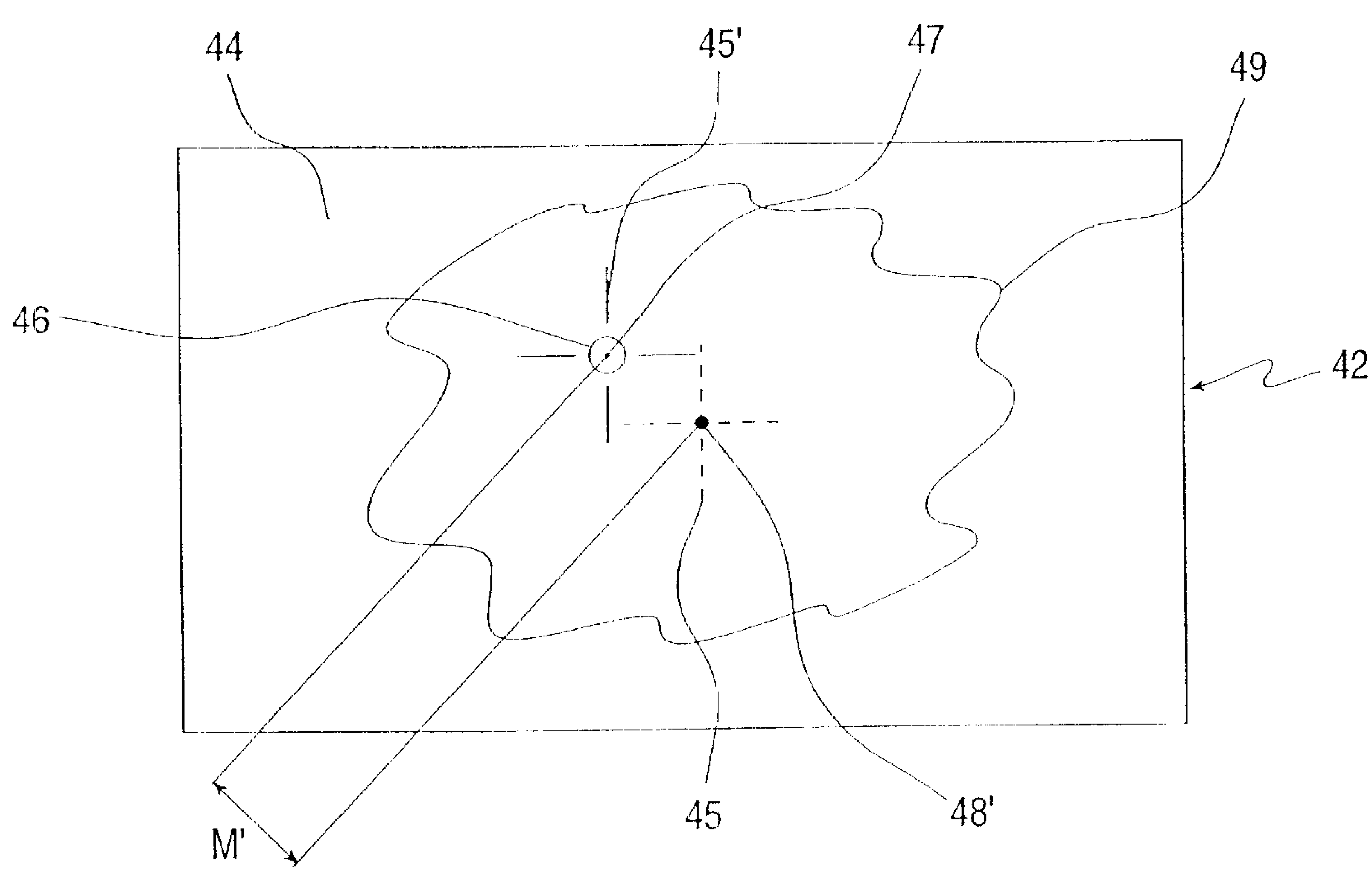


FIG.4A

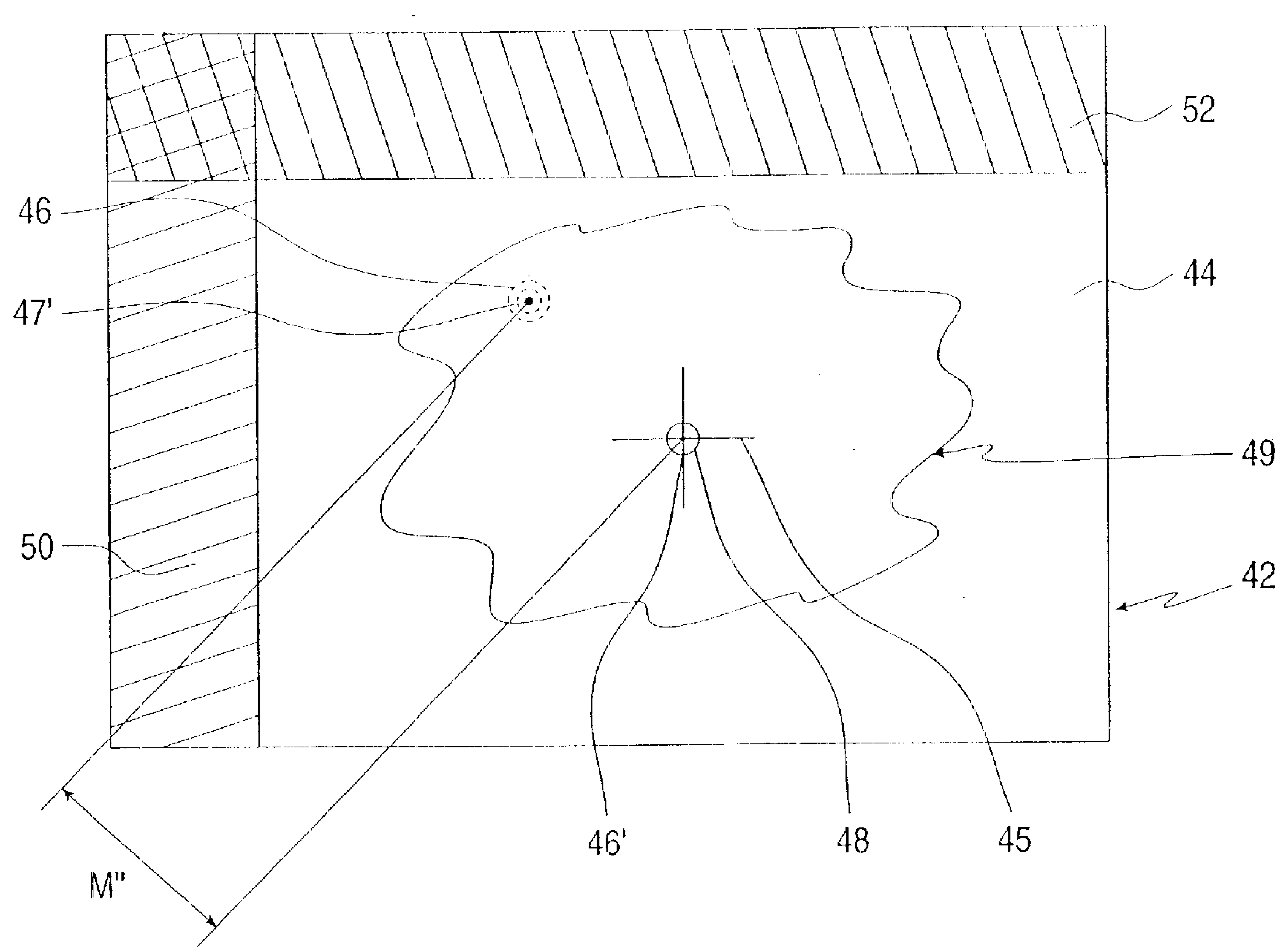


FIG.4B

IN-ACTION BORESIGHT

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to an in-action boresight for laser designation systems.

Modem weapon systems, which employ laser-guided bombs and missiles, require highly accurate alignment of their designation systems in order to achieve a high probability of target acquisition. Traditional methods of achieving this involve ground-based pre-flight calibration of detectors with their corresponding designator, commonly known as boresighting. Ground-based boresight systems are typically robust, heavy and bulky. After ground-based boresighting has been conducted, however, misalignments can develop between the detectors and designators due to environmental conditions, i.e. mechanical and thermal loads including vibrations, shocks and temperature variation. These misalignments can significantly degrade the performance of the designation systems.

To overcome the misalignment problem, in-flight boresight systems have been developed which can be operated a short time prior to weapon operation. Thus, the misalignments that could normally have occurred from boresighting to designator operation are significantly reduced. These systems, however, are typically made up of a large number of optical components which have the potential for introducing further thermo-optical errors and are prone to in-flight misalignment. Furthermore, current methods rely on local heating of specific types of targets, such as ceramics, using laser radiation in order to generate hot-spots, which are then detected by sensor systems. These methods have number of drawbacks, which are discussed below.

As an example, consider FIG. **1** which shows a target **500** where a laser beam (not shown) is incident on the target surface **502**, thereby generating laser spot **504**. Heat is conducted by target **500** and this results in a temperature distribution on target surface **502**. Concentric closed loops **506**, **508** and **510** are isotherms (lines of constant temperature on target surface **502**) and indicate a typical temperature distribution caused by laser spot **504**. The temperature is highest at laser spot **504** and decreases with radial distance. It will be readily appreciated that isotherms **506**, **508** and **510** are in general non-circular and non-symmetric around laser spot **504**. This is due to asymmetric conduction within the material that makes up target **500**. Thus, a sensor (not shown) that is operative to detect the local heating which results from laser spot **504**, will incorrectly detect a center **512** for example, instead of the correct center **501** of laser spot **504**.

The above description illustrates a number of major drawbacks of current boresight systems. Firstly, a period of time, which is non-negligible when compared with the time required for boresighting, is required to heat target surface **502** at the center **501** of laser spot **504** to a temperature that allows sensor detection (typically 25 degrees Celsius above target surface temperature). Secondly, a specific target type is required, such as certain ceramics, which has the particular conductive properties required for generating thermally detectable laser spot. Thirdly, asymmetric conduction on the target surface, as depicted graphically in FIG. **1**, can result in incorrect detection of the laser spot center, thereby degrading the accuracy of the system. Fourthly, in order to effect thermal detection, a large number of additional optical components must be added to the designation system. As

mentioned above, these additional optical components increase the probability of in-flight misalignment and reduce accuracy.

There is therefore a need for an accurate and rapid in-action boresight which has a minimum of additional optical components. The system should not rely on laser heating of specific targets, but should rather detect an optical laser spot. This would both increase the system accuracy and eliminate the time required for heating a target, thereby reducing the overall boresighting time. Furthermore, the system should not be limited to a specific target type, but should allow boresighting on a variety of targets.

SUMMARY OF THE INVENTION

The present invention is a method for in-action boresighting of designation systems.

According to the teachings of the present invention there is provided, a method for boresighting of a designation system, including a tracker responsive to a detector with reference to an indicator, comprising the steps of (a) directing a beam of light at a target, using a light source, so that the beam of light is reflected from a spot on the target while the spot temperature remains substantially constant; (b) focusing at least part of the reflected light as an image on the detector; and (c) determining a misalignment of the indicator and image.

There is furthermore provided, in a boresighting system for aligning an indicator with an image of a spot on a target, a method of displaying the alignment, comprising the steps of providing a video monitor; and displaying a representation of the indicator together with a representation of the image on the video monitor.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. **1** is a schematic depiction of a target with a laser spot incident on its surface (prior art);

FIG. **2** is a schematic depiction of a designation system constructed and operative according to the teachings of the present invention;

FIG. **3** is a schematic depiction of a video image before boresighting;

FIG. **4**A is a schematic depiction of a video display after boresighting by moving a cross-hair; and

FIG. **4**B is a schematic depiction of a video display after boresighting by moving displayed pixels.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The principles and operation of the in-action boresight according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring again to the drawings, FIG. **2** shows the designation system **10**, which is made up of a laser designator **14**, receiving optics **28** and a detector **16**, which are all mounted on a rigid gimbaled base **12**. Rigid gimbaled base **12** is required for the mounting of all components so as to minimize the possibility of misalignment between the various components. A synchronization line **13** synchronizes the operation between laser designator **14** and detector **16**. A tracker line **17** connects detector **16** to a tracker **11**.

Preferably, tracker **11** is connected to a video monitor **21** via a video line **19**. Designation system **10** is positioned at a distance R from a target **22**, where R is referred to as the range-to-target. Target **22** is usually remote, relative to designation system **10**, such that R is typically greater than 1500 meters.

In brief, the objective of boresighting is to align an indicator, such as a cross-hair (not shown), encoded in tracker **11**, with a laser spot image (not shown). After boresighting is complete, typically a cross-hair indicates the location of a laser spot center on target **22**. The indicator and laser spot image may be simultaneously represented as a video image. In a preferred embodiment of the present invention, a cross-hair and laser spot image are displayed simultaneously on video monitor **21**. Boresighting of designation system **10** is achieved according to four main stages, namely: stage I—designation; stage II—laser-spot detection; stage III—signal processing; and stage IV—misalignment correction. These stages must be carried out sequentially, starting with stage I and ending with stage IV. The features of each of the stages, as well as their interrelation, are described in detail below.

In Stage I, the purpose of laser designator **14** is designating, i.e. creating a laser spot **26** on target **22**. As a preferred embodiment, laser spot **26** is formed on the surface **24** of target **22**. If target **22** is a diffuse body, such as a cloud, water droplets or even pollution, laser spot **26** can also be formed on particles within target **22**. Laser designator **14** is typically a pulsed infra-red or visible-light laser which can be pulsed at a wide range of frequencies (alternatively pulses per second, PPS). Laser designator **14** is activated in external triggering mode by detector **16** via synchronization line **13**, thereby producing laser beam **20**. Laser beam **20** is directed towards target **22** and is incident on the target surface **24**. Incident laser beam **20** creates an optical laser spot **26** on target surface **24**, which is reflected from surface **24** and produces a reflected beam which is referred to herein as the laser echo **27**. Optical laser spot **26** is "optical" in the sense that laser beam **20** is merely reflected from surface **24** and does not appreciably change the temperature at the location of target **22** where it is incident. Thus, laser echo **27** can include visible, infra-red or near infra-red wavelengths. In general, target surface **24** may be composed of any partially reflective substance: even certain atmospheric conditions or clouds constitute suitably reflective surfaces. It should be emphasized that the purpose of laser beam **20** is not to cause local heating of target surface **24**, but rather to generate an optical laser spot **26**.

In stage II, target detection, laser echo **27** from optical laser spot **26** is incident on receiving optics **28**. Laser echo **27** is focused by means of receiving optics **28** resulting in focused beam **29** which is incident on detector **16**. To effect detection of laser echo **27**, detector **16** incorporates a sensor **15** of some kind. Typical examples of sensor **15** include Forward-Looking Infra-Red (FLIR) sensors or Charge-Coupled Device (CCD) such as GICCD and EBCCD sensors, for example. Detector **16** triggers and synchronizes laser designator **14**. This means that a laser pulse is initiated by detector **16** and then the detector integration time is set to a time-frame window on which laser echo **27** is expected to be received. This window corresponds to any reasonable range to target R. A range gate is employed to eliminate spurious light signals from short ranges (typically less than 1500 meters). Thus parallax errors, which could cause misalignment, are eliminated. The focusing of beam **29**, which is incident on detector **16**, results in the formation of a laser spot image **23** on the surface **18** of sensor **15**. Background light (not shown), from the target for example, is also incident on sensor surface **18**. All light signals incident on sensor surface **18** are received by detector **16** and transferred via tracker line **17** to tracker **11**.

Part of the function of tracker **11** is to distinguish between the coordinates of laser spot image **23** and background light that is incident on sensor surface **18**. (The preferred method employed to achieve this is discussed later in detail.) Coordinates of the center (not shown) of laser spot image **23** and background light, which are stored as successive video frames in tracker **11**, can be converted into a video image **40** (see FIG. **3**) and transferred via video line **19** to video monitor **21** where these coordinates are visually displayed. It is pointed out that video image **40** can be stored or displayed in a variety of virtual or physical forms, such as random-access memory, magnetic tape, etc.

FIG. **3** is a schematic depiction of a video image **40**, showing a laser spot image **46**, background light **49** and a cross-hair **45**. Laser spot image **46** is located with its center at a spot image center **47** and cross-hair **45** is located with its center at a cross-hair center **48**. Cross-hair **45** may be synthetically generated on video image **40** with its coordinates encoded in tracker **11** (see FIG. **2**). Thus, video image **40** simultaneously represents laser spot image **46**, cross-hair **45** and background light **49**. In general, laser spot image **46** and cross-hair **45** are not initially coincidental (if laser spot image **46** and cross-hair **45** are coincidental, then the system is boresighted). The misalignment, between spot image center **47** and cross-hair center **48** is designated M in the figure.

The primary purpose of stage III, Signal Processing, is to determine misalignment M. This function is performed by tracker **11**, which computes the misalignment M between spot image center **47** and cross-hair center **48**. The signal-to-noise-ratio (SNR) of laser spot image **46** is proportional to the reflectivity of target surface **24** and inversely proportional to the range-to-target R. Thus, when a combination of low target reflectivity and range-to-target R results in a low SNR, the tracker **11** must integrate several (e.g. 20 to 40) video image frames in order to accurately detect spot image center **47**. A preferred method for achieving this is discussed below.

Coordinates of laser spot image **23** and cross-hair **45**, which are encoded in tracker **11**, can be transferred via video line **19** to video monitor **21**, for visual display, much like that shown in FIG. **3**. Cross-hair **45** may be synthetically generated on video display **44** with its coordinates encoded in tracker **11** (see FIG. **2**). In general, a video display image processed by tracker **11** contains laser spot image **46** as well as background light **49**.

In general, a video frame processed by tracker **11** contains laser spot image **46** as well as background light **49**. Laser designator **14** is limited in that it can only operate at a maximum frequency of approximately 15 pulses per second (PPS). Thus, a video format is selected which is some multiple of laser designator **14** operating frequency. For example, in order to detect only laser spot image **46**, laser designator **14** is triggered at one half of the video frame rate of video monitor **21**. Thus, if the video frame rate is 30 Hz, such as in RS170 format, laser designator **14** is triggered at 15 pulses per second (PPS) which is half the RS170 format frame-rate. Alternatively, if the video frame rate is 25 Hz, such as in CCIR format, laser designator **14** is triggered at 12.5 PPS. This results in the reception of a laser spot image on every even video frame and an image with no laser spot on every odd video frame, or vice versa. Tracker **11** then integrates the even frames in a first memory bank **32** and the odd frames in a second memory bank **34**. In this manner, tracker **11** processes laser spot image **46** in first memory bank **32** and simply discards background light **49**, from second memory bank **34**, simultaneously.

Due to the short integration time, only laser spot image **46** is stored in first memory bank **32**, because background light **49** data does not exceed inherent tracker **11** noise levels. In this manner tracker **11** accurately determines spot image center **47**. At this point, tracker **11** contains the coordinates of both spot image center **47** and cross-hair center **48**. Thus, tracker **11** computes a misalignment M between spot image center **47** and cross-hair center **48**.

In stage IV, Misalignment Correction, boresighting is completed in tracker **11**, by aligning spot image center **47** and cross-hair center **48**. For visual display, it is desirable to keep cross-hair **45** as close as possible to the center of video display **44**. Two preferred methods are employed to achieve this. The first method is described with respect to FIG. **4**A and the second method is described with respect to FIG. **4**B.

The first method is often employed when spot image center **47** of laser spot image **46** is sufficiently close to the center of video display **44** as depicted in FIG. **4**A. In this instance, boresighting is achieved by moving cross-hair **45** from a first cross-hair center **48'** to a second cross-hair center that is coincidental with first spot image center **47**, which corresponds to misalignment M'. Thus, after boresighting, the center of cross-hair **45'** is coincidental with first spot image center **47** and is close to the center of video display **44**.

The second method is often employed when a first spot image center **47'** of laser spot image **46** is not sufficiently close to the center of video display **44** as depicted in FIG. **4**B. Here, the misalignment between first spot image center **47'** and cross-hair center **48** is M". In this instance, boresighting is achieved by moving the entire video display **44**, excluding cross-hair **45**, to a new matrix of pixels. In general, the display of the correction of misalignment M" is achieved by utilizing vertical columns of synthetic pixels **50** on the side of video display **44** and horizontal rows of synthetic pixels **52** at the top (or bottom) of video display **44**. For example, if the display is moved towards the left-hand side such that vertical columns of synthetic pixels **50** are added to video display **44**, then corresponding columns of pixels (not shown) on the right-hand side of video display **44** are removed from video display **44**. Thus video display **44** maintains its original size. In this manner the entire video display **44** is moved laterally and longitudinally such that a second spot image center of laser spot image **46'** is coincidental with cross-hair center **48**, and is thus close to the center of video display **44**.

It will be appreciated that the above invention fulfills the need for an accurate and rapid in-action boresight which has a minimum of additional optical components. Boresighting is based on the detection of an optical laser spot and, as such, eliminates the need for targets heating. Thus accuracy is increased and the additional time required for heating a target is eliminated. Furthermore, boresighting can be performed on a variety of targets, thereby increasing flexibility and versatility.

It will be further appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the spirit and the scope of the present invention.

What is claimed is:

1. A method for boresighting of a designation system, including a tracker responsive to a detector, comprising the steps of:

(a) directing a beam of light at a target, using a light source, so that said beam of light is reflected from a spot on said target while a temperature of said target at said spot remains substantially constant and unchanged from what said temperature was prior to said directing of said beam of light at said target;

(b) focusing at least part of said reflected light as an image on the detector; and

(c) determining a misalignment of an indicator encoded in the tracker and said image.

2. The method for boresighting of a designation system as recited in claim **1**, wherein said beam of light is a laser beam.

3. The method for boresighting of a designation system as recited in claim **2**, further comprising the step of:

(d) displaying simultaneously, on a video monitor, said image along with the indicator.

4. The method for boresighting of a designation system as recited in claim **3**, wherein said determining is effected by steps including:

(i) integrating said image and background light together in a first memory bank; and

(ii) integrating only said background light in a second memory bank.

5. The method for boresighting of a designation system as recited in claim **3**, wherein said indicator is displayed on said video monitor as a cross-hair.

6. The method of claim **1**, wherein said target is a diffuse body.

* * * * *